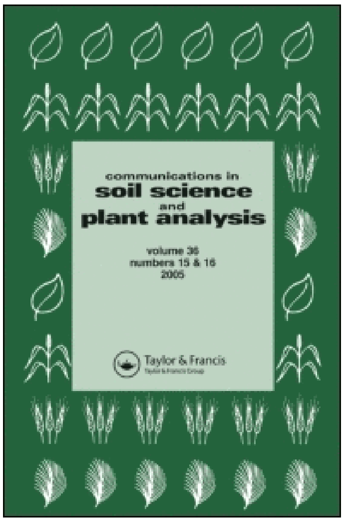

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Properties of Termite Mound Soils and Responses of Rice and Bean to Nitrogen, Phosphorus, and Potassium Fertilization on such Soil

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ABSTRACT

Termite mounds are very common in Oxisols of Cerrado region of Brazil where land is either under forest or long term pasture. The objective of this study was to characterize textural and chemical properties of soils derived from these termite mounds and to determine the growth response of rice and common bean to soil applied nitrogen (N), phosphorus (P), and potassium (K) fertilization. Soil samples were collected from 20 termite mounds located on

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the experimental station farm Capivara of National Rice and Bean Research Center, Santo Antônio de Goiás, Brazil. Average value of clay content was $354\,g\,kg^{-1}$, silt was $217\,g\,kg^{-1}$, and sand was $429\,g\,kg^{-1}$. Average soil pH was 5.7, P was $3.2\,mg\,dm^{-3}$, K was $150\,mg\,dm^{-3}$, and organic matter content was $32\,g\,dm^{-3}$. Average cation contents ($mmol\,dm^{-3}$) for calcium (Ca), magnesium (Mg), aluminum (Al), and Al + H were 36, 18, 1.7, and 78, respectively. Average micronutrient contents ($mg\,dm^{-3}$) for copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) were 2.8, 3.2, 135, and 78, respectively. Average cation saturation was 45%, Al saturation 2.8%, Ca/K ratio 10.7, Ca/Mg ratio 2.1, and Mg/K ratio 5.1. On average, soil fertility of termite mounds was higher than that of the Oxisols soils surrounding the mound. Upland rice (*Oryza sativa* L. cv. Maravilha) and common bean (*Phaseolus vulgaris* L. cv. Perola) grown on a representative termite mound soil responded significantly to applied N and P. However, with the exception of grain yield of common bean, these crops did not respond to K fertilization.

Key Words: Cation saturation; Aluminum saturation; Grain yield; Soil chemical properties.

INTRODUCTION

In the central part of Brazil there are about 205 million ha of land area, locally known as Cerrado; the predominant soils of this region are Oxisols. In this region termite mounds are very common, especially on land under pasture or forest. Soil tillage practices, application of biocides, reduction of vegetative cover, and the consequent changes in microclimate are known to decrease the survival and reproduction of soil microarthropods in arable fields.[1] Grasse[2] reported that more than 2000 species of termites are currently known to exist, and a majority of them are commonly found in the tropics.

Termites process considerable quantities of materials in their mound building activities, thereby strongly influencing mound soil properties compared with those of surrounding soils.[3–5] Such modifications of soil have a great impact on the vegetation, through spatial and temporal effects, even when the termite colony is dead and the mound material is subject to erosion.[6,7] Modifications of soil physical and chemical properties by termites have been reported,[3,8,9] however, only limited studies have involved the effects of such changes on crop growth. The objective of this study was to characterize terxtural and chemical properties of termite mound soils in the Cerrado region of Brazil and to further assess the influence of N, P, and K fertilization on the growth responses of upland rice and common bean grown on a representative termite mound soil.

MATERIALS AND METHODS

Soil samples were collected from 20 termite mounds located on the Embrapa Rice & Bean Research Center's Experimental Station Farm, Capivara, Santo Antonio de Goias, GO, Brazil. A major part of the soils on this farm are classified as Oxisols according to the USA Soil Taxonomy Classification System. Soil textural and chemical analyses were performed according to methodology described in the soil analysis manual of EMBRAPA.[10] Soil pH was determined in a 1:2.5 soil–water ratio. Phosphorus, K, and the micronutrients were extracted by the Mehlich 1 extracting solution ($0.05\,M$ $HCl + 0.0125\,M$ H_2SO_4). Phosphorus was determined colorimetrically, K by flame photometry, and micronutrients by atomic absorption spectrophotometry. Calcium, Mg, and Al were extracted with 1 M KCl. Aluminium was determined by titration with NaOH, and Ca and Mg by titration with EDTA. Organic matter was determined by the Walkley-Black method. Cation saturation and Al saturation were calculated using the following formulas:

$$\text{Cation saturation} = \left(\sum Ca^{2+}, Mg^{2+}, K^{+}\right)/(\text{CEC}) \times 100$$

$$\text{Where, cation exhange capacity (CEC)} = \sum (Ca^{2+}, Mg^{2+}, K^{+}, H^{+}, Al^{3+})$$

$$\text{Al saturation of effective cation exchange capacity (ECEC)} = (Al^{3+}) \Big/ \left(\sum Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+}\right) \times 100$$

$$\text{Where effective cation exchange capacity (ECEC)} = \sum (Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+})$$

Soil from Number 1 termite mound was used to determine responses of upland rice (*Oryza sativa* L. cv. Maravilha) and common bean (*Phaseolus vulgaris* L. cv. Perola) to N, P, and K fertilization. Plants were grown in a greenhouse at the National Rice and Bean Research Center of Embrapa. There were five treatments, which include a control (without fertilizer addition), adequate level of NPK (200 mg N, 200 mg P, and 200 mg K kg^{-1} of soil), without N (PK), without P (NK) and without K

(NP). With the exceptions of the control and without N (PK) treatments, all the other treatments received 180 mg N as topdressing. Topdressing of N for rice was done 45 days after sowing and that for bean was done at 35 days after sowing. Nitrogen was applied as urea, P as triple superphosphate, and K as potassium chloride. Soils of all treatments received dolomitic lime at the rate of $2\,g\,kg^{-1}$ of soil four weeks before sowing and incubated through wetting and drying cycles for six weeks. Plants were grown in plastic pots, each containing 5 kg of soil. Four plants were maintained per pot after germination. A complete randomized design was used and treatments were replicated four times. At harvest grain yield, plant dry matter and yield components were determined. Analysis of variance was used to evaluate the effects of treatments and Tukey's test, at 0.05 probability level, was used to compare treatment means when the analysis of variance indicated a significant treatment effect.

RESULTS AND DISCUSSION

Soil Textural Properties

Clay content varied from 260 to $505\,g\,kg^{-1}$, silt 110 to $295\,g\,kg^{-1}$, and sand 200 to $575\,g\,kg^{-1}$ (Table 1). Average values of 20 samples were $354\,g\,kg^{-1}$ clay, $217\,g\,kg^{-1}$ silt, and $429\,g\,kg^{-1}$ sand. On an average, Cerrado Oxisols contain $420\,g\,kg^{-1}$ clay, $85\,g\,kg^{-1}$ silt, and $490\,g\,kg^{-1}$ sand.[11] Clay and sand contents of termite mound soils were near the range reported for Oxisols in the literature, however, silt content was substantially higher. This indicates that termite action increased silt content of mounds and probably increased the nutrient-supplying capacity of the soil. This may happen because termites generally select the smaller particles from within the profile; material brought to the surface are commonly finer in texture and may have different clay mineral composition than those of the original surface.[3] Lavelle et al.[3] also reported that the epigeal mounds built by termites are usually fine textured and have cemented hard and massive structures that shed almost all the water that impinges on them.

Soil pH, Calcium, Magnesium, Aluminum, Hydrogen, and Aluminum

Soil pH varied from 4.7 to 6.3; extractable cations ($mmol\,dm^{-3}$) such as Ca varied from 20 to 81; Mg varied from 7 to 29; Al varied from 0 to 15; and H + Al varied from 42.4 to 257.6 (Table 2). Average values for

Table 1. Textural properties of 20 soil samples of termite mounds in Cerrado region of Brazil and compared with average properties Oxisols of the region.

Soil	Clay ($g\,kg^{-1}$)	Silt ($g\,kg^{-1}$)	Sand ($g\,kg^{-1}$)
1	320	200	480
2	310	235	455
3	350	190	460
4	310	260	430
5	345	215	440
6	450	230	320
7	505	295	200
8	260	295	445
9	505	215	280
10	435	205	360
11	275	165	560
12	305	285	410
13	365	155	480
14	315	220	465
15	420	110	470
16	325	210	465
17	310	220	470
18	330	265	405
19	310	115	575
20	330	250	420
Minimum	260	110	200
Maximum	505	295	575
Average	354	217	429
SD	71	52	87
Oxisols[a]	420	85	490

[a]Lopes.[11]

the termite mound soils were: pH 5.7, extractable cations ($mmol\,dm^{-3}$) Ca 36, Mg 18, Al 1.7, and H + Al 77.9. Generally, pH value in water of Oxisols of Cerrado region varied from 4.9 to 6.3 with an average value of about 5.4.[11–13] The pH values of termite mound soils were within this range; however, the average value was somewhat higher. Hence, termite activities lead to an increase in soil pH. This improvement may be related to increases in extractable Ca and Mg and decrease in extractable Al (Table 2). Average values of the extractable Ca, Mg, and Al in Oxisols of Cerrado region reported in the literature are 2.5, 0.9, and 5.6 $mmol\,dm^{-3}$, respectively.[11–13] The substantial increase in levels of extractable Ca and Mg may be related to observation that almost all termites feed on dead

Table 2. Chemical properties of 20 soil samples of termite mounds of the Cerrado region of Brazil and compared with average properties of Oxisols of the region.

Soil	pH in water	Ca (mmol dm^{-3})	Mg (mmol dm^{-3})	Al (mmol dm^{-3})	H + Al (mmol dm^{-3})
1	6.2	30	14	0	53.6
2	5.8	35	17	1	58.2
3	5.6	20	15	1	73.8
4	5.8	30	20	1	49.0
5	5.9	44	25	1	50.3
6	6.2	37	21	0	45.4
7	5.2	44	24	3	115.8
8	5.8	31	20	1	61.3
9	5.7	27	17	1	64.5
10	5.8	30	13	1	5.9
11	5.0	38	7	15	257.6
12	5.3	20	13	1	6.1
13	5.8	29	13	1	60.0
14	5.8	22	9	1	59.7
15	5.8	26	13	1	58.2
16	6.2	31	17	0	42.4
17	4.7	81	29	4	180.3
18	6.0	40	27	1	92.4
19	6.3	36	22	0	51.3
20	5.6	67	20	0	67.1
Minimum	4.7	20	7	0	42.4
Maximum	6.3	81	29	15	257.6
Average	5.7	36	18	1.7	77.9
SD	0.4	15	6	3	52.5
Oxisols[a]	5.4	2.5	0.9	5.6	50.0

[a]Lopes,[11] Cochrane,[12] and Fageria and Stone.[13]

organic matter, breaking it down in a complete way, sequestering soil organic matter and plant nutrients in their mounds.[3]

Soil Phosphorus, Potassium, Copper, Zinc, Iron, Manganese, and Organic Matter

In the soil samples analyzed, extractable ions (mm dm^{-3}) such as P varied from 0.6 to 9, K from 86 to 266, Cu from 1.1 to 4.9, Zn from

0.8 to 6, Fe varied from 63 to 517, Mn from 11 to 165, and organic matter content varied from 19 to 93 g dm^{-3} (Table 3). Average values of these soil ionic properties were (mg dm^{-3}): P 3.2, K 150, Cu 2.8, Zn 3.2, Fe 135, Mn 78, and organic matter content of 32 g dm^{-3}. Average values of these soil chemical properties reported in the literature for Oxisols of the Cerrado region are P around 2 mg dm^{-3}, K around 31 mg dm^{-3}, Cu and Zn approximately 0.6 mg dm^{-3}, approximate values of Fe 33 mg dm^{-3}, Mn 8 dm^{-3}, and organic matter 22 g dm^{-3}.[11–13] Hence termite activities

Table 3. Chemical properties of 20 soil samples of termite mounds of the Cerrado region of Brazil and compared with average properties of the Oxisols of the region.

Soil	P (mg dm^{-3})	K (mg dm^{-3})	Cu (mg dm^{-3})	Zn (mg dm^{-3})	Fe (mg dm^{-3})	Mn (mg dm^{-3})	OM (g dm^{-3})
1	1.8	206	2.8	2.9	125	60	27
2	6.2	154	4.0	5.0	115	72	23
3	4.4	154	3.6	3.2	116	69	20
4	2.1	172	4.9	1.8	90	165	21
5	2.1	137	4.9	5.1	107	165	21
6	4.4	249	3.5	3.9	108	59	22
7	2.3	94	4.0	2.9	118	143	42
8	2.5	87	3.1	2.8	63	80	22
9	9.0	249	2.3	5.4	74	43	31
10	2.6	120	1.9	2.2	100	24	23
11	6.1	95	1.1	2.7	517	143	93
12	1.0	92	1.9	3.3	110	12	26
13	7.5	120	1.8	6.0	107	15	23
14	1.9	154	1.8	2.0	132	11	26
15	0.6	129	1.6	0.8	97	32	19
16	1.2	154	2.3	2.3	87	48	22
17	2.8	86	1.8	2.5	253	143	74
18	3.2	206	2.9	4.2	220	74	47
19	1.9	266	3.6	1.6	126	79	20
20	1.2	137	1.8	3.7	44	132	32
Minimum	0.6	86	1.1	0.8	63	11	19
Maximum	9.0	266	4.9	6.0	517	165	93
Average	3.2	150	2.8	3.2	135	78	32
SD	2.3	56	1.1	1.4	101	52	19
Oxisols[a]	2.0	31	0.6	0.6	33	8	22

[a]Lopes,[11] Cochrane,[12] and Fageria and Stone.[13]

improved the fertility of these Oxisols of the Cerrado region. Arshad,[14] Spain and McIvor,[15] and Okello-Oloya and Spain[16] also reported relatively higher fertility of termite mound soils compared with that of surface soils distant from mounds. Potassium contents of these termite mound soils were increased much more than that of other nutrients. This may be related to feeding termites on dead cereal and legume straw, which generally contain higher concentrations of potassium than other nutrients. Fageria et al.[17] determined K content of grain and straw of rice, common bean, wheat, and cowpea grown on an Oxisol of Central Brazil and concluded that K content in the shoot of rice was 78%, in wheat 72%, in bean shoot 43%, and in cowpea it was 49% of the total uptake.

Soil Cation Saturation, Aluminum Saturation, Calcium/Potassium Ratio, Calcium/Magnesium Ratio, and Magnesium/Potassium Ratio

Cation saturation varied from 16 to 57% with an average value of 45%. Similarly, Al saturation of effective cation exchange capacity varied from 0 to 24% with an average value of 2.8% (Table 4). The Ca/K ratio varied from 4.2 to 36.8 with an average value of 10.7, Ca/Mg from 1.3 to 5.4 with an average value of 2.1, and Mg/K from 2.3 to 13.2 with an average value of 5.1. Average natural cation saturation of Oxisols of Cerrado region is approximately 30%[11,12] and Al saturation of effective cation exchange capacity is around 20%.[11,12] Thus on average, termite activities increased cation saturation and decreased Al saturation of termite mound soils. Such soil chemical changes may be related to the substantial increases in Ca, Mg, and K content and decreases in Al levels. Average values of Ca/K, Ca/Mg, and Mg/K of Oxisols of Cerrado region are approximately 1.2, 0.7, and 2.2, respectively.[11,12] Values reported in our study for the termite mound soils were much higher than average values reported for Oxisols.[11,12]

Crop Responses to Nitrogen, Phosphorus, and Potassium Fertilization

Dry weights of shoot and grain of upland rice and common bean grown on termite mound soil were significantly increased by the NPK treatment (Table 5). Number of panicles in rice and pods in bean were also increased with NPK fertilization, however, this effect was significant

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Table 4. Saturation of cations and Al, and ratios of Ca/K, Ca/Mg, and Mg/K of 20 soil samples of termite mounds of Cerrado region of Brazil compared with properties of Oxisols of the region.

Soil	Cation saturation (%)	Al saturation (%)	Ca/K	Ca/Mg	Mg/K
1	48	0.0	5.6	2.1	2.6
2	49	1.8	9.0	2.1	4.4
3	35	2.5	5.1	1.3	3.9
4	53	1.8	6.8	1.5	4.6
5	59	1.4	12.6	1.8	7.1
6	57	0.0	5.0	1.5	3.3
7	38	4.1	18.3	1.8	10.0
8	47	1.9	14.1	1.6	9.1
9	44	2.0	4.2	1.6	2.7
10	46	2.1	9.7	2.3	4.2
11	16	24.0	15.8	5.4	2.9
12	36	2.8	8.3	1.5	5.4
13	43	2.2	9.4	2.2	4.2
14	37	2.8	5.6	2.4	2.3
15	42	2.3	7.9	2.0	3.9
16	55	0.0	8.0	1.8	4.4
17	38	3.4	36.8	2.8	13.2
18	44	1.4	7.6	1.5	5.1
19	56	0.0	5.3	1.6	3.2
20	57	0.0	19.1	3.4	5.7
Minimum	16	0.0	4.2	1.3	2.3
Maximum	57	24.0	36.8	5.4	13.2
Average	45	2.8	10.7	2.1	5.1
SD	10	5.1	7.6	0.9	2.8
Oxisols[a]	30	20	1.2	0.7	2.2

[a]Lopes[11] and Cochrane.[12]

only for panicle number in rice. The increase in shoot and grain yield of upland rice with the NPK treatment was 140 and 188%, respectively. Similarly, NPK treatment increased bean dry weight of shoots by 266% and grain yield increase by 95%. In upland rice PK and NK treatment reduced shoot dry matter grain yield and number of panicles compared with NPK treatment. Similarly, in bean also PK and NK treatments decreased shoot dry weight and grain yield compared to NPK treatment. The NP treatment had no significant effect on shoot dry weight of rice and bean crops. However, it reduces grain yield of common bean

Table 5. Responses of the upland rice and common bean to N, P, and K fertilization on a termite mound soil of Cerrado region of Brazil.

Treatment	Shoot dry wt. (g/pot)	Grain yield (g/pot)	Number of panicles or pods per pot
Upland rice			
Control	38.33 b*	18.40 b	12.50 b
NPK	91.95 a	52.93 a	31.75 a
PK	48.43 b	29.93 b	20.50 ab
NK	57.85 b	25.53 b	15.50 b
NP	91.10 a	50.56 a	28.50 a
Common bean			
Control	13.98 b	15.15 b	20.50
NPK	51.20 a	29.50 a	30.25
PK	25.53 b	16.15 b	16.75
NK	16.20 b	15.20 b	18.75
NP	49.50 a	19.48 b	22.50

*Means in the same column followed by the same letter are not significantly different at the 5% probability level according to Tukey's studentized test.

compared to NPK treatment. In common bean number of pods per pot was not significantly influenced by fertilizer treatments. The increase in grain yield of rice was due to increase in panicle number, and increase in bean yield was due to increase in pod numbers. Fageria and Baligar,[18] Fageria and Costa,[19] and Fageria et al.[20] also reported significant increases in yields of upland rice and common bean with the application of N and P fertilization of crops grown on an Oxisols of Central Brazil. the nonresponse of rice and some growth parameters of bean to K fertilization may be related to higher K level in the termite mound soil on which these two crops were grown. Fageria et al.[21] reported that upland rice responded to K fertilization on an Oxisols when levels of this element were below 50 mg dm^{-3}. The lowest K value of the soil used in our study was 86 mg dm^{-3}. Similarly, Fageria et al.[22] reported that in Cerrado Oxisols, common bean responded to K fertilization only when soil K was below 45 mg dm^{-3}.

CONCLUSIONS

Termite activities significantly influenced the soil textural and chemical properties of Oxisols. Silt content and almost all desirable soil chemical properties were improved and soil acidity in terms of pH and Al content and Al saturation were decreased by the termite activities. The increase in soil K content was relatively high as compared to that of other essential plant nutrients. More attention should be paid to the often fertile soil accumulated in structures and mounds built by termites in Cerrado region of Brazil. The exploitation of this improved soil with high fertility is possible for the gardening, lawn, and ornamental industries by reducing costs of fertilization. More research should be conducted to evaluate feasibility of such practices on a larger scale.

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